# APPLICATION UNDER UNITED STATES PATENT LAWS

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Invention: NON-PRIMARY DETONATORS

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☐ Provisional Application

☐ Regular Utility Application

☐ Continuing Application
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☒ PCT National Phase Application

☐ Design Application

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☐ Plant Application

☐ Substitute Specification
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# SPECIFICATION

<u>Non-primary Detonators</u>

## Field of the Invention

5      The present invention relates to explosive detonators comprising compositions which are characterized by being essentially free from molecular primary explosives, to compositions suitable for use in detonators, and to the manufacture of detonators.. The invention further relates to initiating elements for use in detonators and to a method of blasting.

10

## Description of the Related Art

Detonators, including electronic, electric and non-electric types, are widely employed in mining, quarrying and other blasting operations. In-hole detonators are generally used to initiate an explosive charge which has been placed in a borehole, while surface detonators are generally used outside of the borehole to initiate one or more explosive initiating signal means such as shock tube or detonating cord.

Modern commercial detonators typically comprise, in the case of an in-hole detonator, a metallic shell which is closed at one end and which contains, in sequence from the closed end, a base charge of a detonating, secondary explosive, such as for example, pentaerythritoltetranitrate (PETN), and a primer charge of a heat-sensitive, detonable, primary explosive, such as for example, lead azide, which is above and adjacent to the base charge. In a delay detonator,

adjacent the primary explosive is an amount of a deflagrating or burning composition of sufficient quantity to provide a desired delay time. Above the delay composition (if present) is an electric match, a low energy detonating cord or shock wave conductor (such as shock tube), or the like, retained in the open end

5    of the metallic shock.

Surface detonators are generally identical to in-hole detonators with the exception that the base charge of high explosive is preferably reduced or omitted to give lower output. The output is preferably reduced to a level sufficient to initiate adjacent shock tube, detonating cord and the like, without, for example,

throwing excessive amounts of shrapnel which can damage nearby lengths of shock tube or cord. This feature of output control is a desirable practise in the design of detonators in order to control the energy output of in-hole and surface detonators.

5       For the purposes of this specification, a primary explosive is defined as an explosive substance which readily develops complete detonation from stimuli such as flame, conductive heating, impact, friction or static electrical discharge, even in the absence of any confinement. In contrast, a secondary explosive can generally only be detonated if it is present in larger quantities or if contained

10    within heavy confinement such as a heavy walled metal container, or by being exposed to significant shock wave or mechanical impact. Examples of primary explosives are mercury fulminate, lead styphnate, lead azide and diazodinitrophenol (DDNP) or mixtures of two or more of these and/or similar substances. Representative examples of secondary explosives are (PETN),

15    cyclotrimethylenetrinitramine (RDX), cyclotetramethylenetetranitramine (HMX), trinitrophenylmethylnitramine (Tetryl) and trinitrotoluene (TNT) or mixtures of two or more of these and/or other similar substances.

The use of lead azide as a heat-sensitive, primary explosive material, or as the sole component of the base charge (in the case of some surface detonator

20    type initiators), is standard practice in the detonator industry. Accordingly, primary explosives, and in particular lead azide, are widely used by this industry.

This use of primary explosives in the preparation of surface and in-hole detonators, and in particular, the use of lead-containing materials such as lead azide, has several serious disadvantages. These include, for example,: (i) that

25    even the presence of a small charge of primary explosive makes a conventional detonator potentially hazardous to handle because of its sensitivity to mechanical deformation or impact; (ii) that the manufacture of the detonator requires the production and handling of significant quantities of sensitive mat rials which require costly handling procedures; and (iii) that detonator manufacturing plants

30    must address the health risks of dealing with potentially toxic materials such as lead, and address the proper disposal of these toxic materials.

Accordingly, due to the desirability of minimizing or eliminating the use of
primary explosives during the production and use of detonators, for, inter alia,
safety and/or toxicity reasons, it would be desirable to provide a detonator which
was essentially free from primary explosives, and in particular, lead azide.

5          One approach to the elimination of primary explosives from detonators has
been the development of primary explosive-free detonators which rely on the
establishment of conditions in the detonator which will cause a secondary
explosive to undergo a "deflagration to detonation transition" (DDT) reaction. In
these DDT detonators, a deflagration reaction is typically initiated in a secondary
10        explosive by a thermal reaction with an igniting device, such as the flame front
from a shock tube, or directly from a heated bridge wire. By suitable confinement
of the secondary explosive, and/or control of the secondary explosive particle
size, morphology, density, and formulation, as well as careful selection of the
initiation means and detonator design, this deflagration reaction is caused to
15        transfer to a detonation reaction which detonation provides sufficient force to
initiate an adjacent base charge, or directly initiate a shock tube or length of
detonating cord attached to the detonator. Examples of these types of DDT
detonators, or other modified detonators, are described in, for example, U.S.
Patent No. 2,400,103 (Cobb), U.S. Patent No. 3,096,714 (Yuill), U.S. Patent No.
20        4,727,808 (Wang et al.), U.S. Patent No. 4,316,412 (Dinegar and Kirkham), PCT
Patent Publication No. WO97/22571 (Dumenko) published June 26, 1997, US
Patent No. 5385098 (Lindquist et al.), and a related European application
numbered as EP-A1-0365503 (Lindquist et al.).

In Dinegar (US 4,316,412) a detonator is described in which a bridgewire is
25        used to initiate a charge of potassium picrate and fine (10 micron) PETN pressed
to a high density, in a burning mode. This reaction then progresses to a
detonation reaction in an adjacent "transition charge" of fin   PETN. The
detonation of this transition charge eff  cts detonation of the adjacent base
charge. This d vice, however, is characterised by high confinement both to th
30        sides around th  two charges and to the back around th  bridgewire. Such  high
confinement in a standard commercial detonator is not possible due to the limited

dimensions of these detonators and is not desirable due to manufacturing difficulties.

In Wang (US 4,727,808), a fine secondary explosive (PETN < 20 micron and specific surface area of 5000-7000 $cm^2/g$) is used as the initiating charge in
5    order to allow a fast pressure build-up to cause the detonation of the adjacent transition charge of a lower density PETN. This detonation reaction causes the base charge of the detonator to detonate. This design, however, depends on a hot ignition source and strong back confinement provided by a small aperture in the confinement element to allow the fast pressure build-up. This detonator has a
10   high degree of complexity in design, and is relatively expensive to manufacture.

Lindquist (US 5385098) describes a DDT detonator comprising a deflagration section having material in the form of a porous granulated material in order to provide a suitable reaction front. The granulated material is preferably a mixture of a secondary explosive and a combustion catalyst which have been
15   granulated to form granules with a weight average particle size between 10 and 2000 microns; and made up of a plurality of primary crystals having a weight average particle size between 0.1 and 100 microns. The combustion catalyst is a material such as carbon, kryolites or compounds of aluminum, manganese, iron, cobalt, nickel, mercury, silver, zinc, lead, chromium, copper, and mixtures thereof.
20   While providing an improved DDT detonator, this device still requires strong confinement, and in particular, back-confinement of the initiating element which back confinement consists of a cup-shaped confinement shell (with an aperture), which surrounds the initiating element. Use of this cup-shaped confinement shell, together with the preferred use by Lindquist, of back-pressing of the initiating
25   element, adds to the manufacturing cost and complexity of the completed detonator.

Thus, while DDT detonators have shown promise for the replacement of standard primary explosive-containing detonators, their reliability and ease-of-manufacture have led to continued interest in developing additional types
30   of primary explosive-free detonators. In order to overcome these difficulti s, other primary explosives-free detonators have been proposed; including devices such

as "flyer" plates (U.S. 3,978,791) or involve the use of lasers (U.S. 3,724,383). However, these have met with little commercial success due to operational and/or manufacturing difficulties.

A further alternative involves the use of high energy pyrotechnics, as
5    described in Canadian patent application No. 2215892.

However, it is still felt in the industry, that it would still be desirable to provide improved performance in a deflagration to detonation transition (DDT) detonator.

Accordingly, in light of the prior art, it would be desirable to provide a
10    composition for use in detonators which is preferably free from primary explosive, and which can be operated without requiring non-standard levels of confinement or the like.

## Summary of the Invention

Accordingly, the present invention provides a detonator comprising:
15            (i) a hollow detonator shell having an open end and a closed end;
            (ii) an igniting device at the open end of said shell;
            (iii) optionally one or more delay elements adjacent said igniting device;
            (iv) an initiating element comprising an initiation portion and
20            optionally a transition portion; and
            (v) optionally a base charge,
characterized in that said initiation portion is at least partially contained within a confinement sleeve and comprises an intimate mixture of a relatively large particle size, porous, powdered explosive having interstitial spaces, and a
25    relatively small particle size, high-burn-rate, pressurizing initiator located within said interstitial spaces.

For the purposes of this application, the term "porous powdered explosive" refers to an explosive material which when loosely poured into a container, allows

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air to pass through the material without a substantial amount of air resistance. The term "powdered" is merely used to indicate that the material is not a liquid or a gas. Preferred materials useful as porous powdered explosives include materials such as pentaerythritoltetranitrate (PETN), cyclotrimethylenetrinitramine

5    (RDX), cyclotetramethylenetetranitramine (HMX), trinitrophenylmethylnitramine (Tetryl), trinitrotoluene (TNT), or combinations thereof. Most preferably, however, the porous powdered explosive is PETN.

When used in the practise of the present invention, the relatively large particle size of the porous powdered explosive creates sufficient interstitial

10   spaces to allow the high-burn-rate, pressurizing initiator to be located within the interstitial spaces even when the mixture is pressed to a desired density within the detonator. Thus, the term "porous" is used to describe a feature of a material to form significant amounts of interstitial spaces contained within the material. A preferred level of porosity is such that the porous, powdered explosive contains,

15   when pressed into place, void spaces of up to 30%, by volume, and more preferably, between 15 and 30% by volume void space.

Further, the shape of the crystals of the porous powdered explosive can also influence the level of interstitial spaces, and thus influence its ultimate reaction properties. For example, a cylindrical configuration would typically allow

20   for the void spaces to have a longer continuous volume when compared to a spherical configuration. Accordingly, cylindrical, prismatic, or generally non-spherical configurations are preferred to spherical or cubic configurations since the void space in the porous powdered explosive would be relatively larger for these configurations. Accordingly, it is preferred that the porous powdered

25   explosive be cylindrical or prismatic in shape and have a crystal aspect ratio of length to width, of at least 3 to 1, and more preferably at least 4 to 1.

As previously stated, the porous powdered explosive is also relatively large when compared with the particl   size of the high-burn-rate pr ssurising initiator. As a general guideline, it is preferred that the crystal particle size of th   porous

30   powdered explosiv   is greater than 10 times, on average, of the size of the high-burn-rate initiator. Further, it is preferred that the porous powdered explosiv

as "flyer" plates (U.S. 3,978,791) or involve the use of lasers (U.S. 3,724,383). However, these have met with little commercial success due to operational and/or manufacturing difficulties.

A further alternative involves the use of high energy pyrotechnics, as described in Canadian patent application No. 2215892.

However, it is still felt in the industry, that it would still be desirable to provide improved performance in a deflagration to detonation transition (DDT) detonator.

Accordingly, in light of the prior art, it would be desirable to provide a composition for use in detonators which is preferably free from primary explosive, and which can be operated without requiring non-standard levels of confinement or the like.

## Summary of the Invention

Accordingly, the present invention provides a detonator comprising:

(i) a hollow detonator shell having an open end and a closed end;

(ii) an igniting device at the open end of said shell;

(iii) optionally a delay element adjacent said igniting device;

(iv) an initiating element comprising an initiation portion and optionally a transition portion; and

(v) optionally a base charge,

characterized in that said initiation portion is at least partially contained within a confinement sleeve and comprises an intimate mixture of a relatively large particle size, porous, powdered explosive having interstitial spaces, and a relatively small particle size, high-burn-rate pressurizing initiator located within said interstitial spaces.

For the purposes of this application, the term "porous powdered explosive" refers to an explosive material which when loosely poured into a container, allows

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air to pass through the material without a substantial amount of air resistance. The term "powdered" is merely used to indicate that the material is not a liquid or a gas. Preferred materials useful as porous powdered explosives include materials such as pentaerythritoltetranitrate (PETN), cyclotrimethylenetrinitramine

5    (RDX), cyclotetramethylenetetranitramine (HMX), trinitrophenylmethylnitramine (Tetryl), trinitrotoluene (TNT), or combinations thereof. Most preferably, however, the porous powdered explosive comprises PETN.

When used in the practise of the present invention, the relatively large particle size of the porous powdered explosive creates sufficient interstitial

10   spaces to allow the high-burn-rate pressurizing initiator to be located within the interstitial spaces even when the mixture is pressed to a desired density within the detonator. Thus, the term "porous" is used to describe a feature of a material to form significant amounts of interstitial spaces contained within the material. A preferred level of porosity is such that the porous, powdered explosive contains,

15   when pressed into place, void spaces of up to 30%, by volume, and more preferably, between 15 and 30% by volume void space.

Further, the shape of the crystals of the porous powdered explosive can also influence the level of interstitial spaces, and thus influence its ultimate reaction properties. For example, a cylindrical configuration would typically allow

20   for the void spaces to have a longer continuous volume when compared to a spherical configuration. Accordingly, cylindrical, prismatic, or generally non-spherical configurations are preferred to spherical or cubic configurations since the void space in the porous powdered explosive would be relatively larger for these configurations. Accordingly, it is preferred that the porous powdered

25   explosive be cylindrical or prismatic in shape and have a crystal aspect ratio of length to width, of at least 3 to 1, and more preferably at least 4 to 1.

As previously stated, the porous powdered explosive is also relatively large when compared with the particle size of the high-burn-rate pressurising initiator. As a general guideline, it is preferred that the crystal particle size of the porous

30   powdered explosive is greater than 10 times, on average, of the size of the high-burn-rate initiator. Further, it is preferred that the porous powdered explosive

has a number average particle size of between 100 and 500 microns, more preferably between 100 and 300 microns, and most preferably between 100 and 200 microns.

Unless otherwise specified, all particle sizes provided are based on number
5    average particle sizes. Also, unless otherwise noted, all percentages are based on weight percentages.

It should be noted, however, that even with a number average particle size of greater than 100 microns, the porous, powdered explosive may contain particles which range from values below 100 microns. However, the number
10   average size is still greater than 100. Further, the porous, powdered explosive may also contain a small portion of a fine powder having a smaller particle size. This fine powder can have, for example, a particle size of less than 20 microns, or less than 10 microns, or even less than 5 microns. Under some circumstances, however, this small amount of fine powder can assist in the fast ignition and rapid
15   pressurization of the larger porous, powdered explosive particles, and thereby improve the efficiency of the transition from deflagration to detonation. The amount of this fine powder is preferably less than 10%, or more preferably, less than 5%, by weight of the porous, powdered explosive, and is not used to calculate the number average particle size of the porous powdered explosive.

20   The ultimate porosity of material utilized can be estimated and or adjusted for a given material by controlling the density of the material. For example, a typical sample of PETN has between 15 and 30% void space when tested at a density of 1.2 to 1.5 g/cc.

The term "high-burn-rate pressurising initiator" refers to a fast burning
25   ignition compound or mixture, which has a fast ignition and which also generates an essentially continuous increase in burn rate as gas pressure increases. Preferably, the high-burn-rate initiator has a linear burn rat  of greater than 1 cm/sec at a pressur  of 2 atmospheres (when measured with a strand burning technique using cylindrical samples of 4 mm diameter or larger, pr  ssed to more
30   than 0.85 g/cc crystal density in a constant pressure bomb as described in Belyaev, A. F. et al.  in "Transition from Deflagration to Detonation in Condensed

Phases", Israel Program for Scientific Translations, Jerusalem, 1975 and Svetlov,
B. S. and Fogel'zang, A. E., "Combustion of fast burning explosives", Comb.,
Expl. and Shock Waves, Vol. 5, No. 1, 51, 1969).

More preferably, the burn rate of the high-burn-rate pressurising initiator

5    increases essentially continuously with pressure and reaches a value of greater
than 2 cm/sec, and still more preferably, greater than 5 cm/sec, at a pressure of
50 atmospheres.

For example, pure potassium picrate has a linear burn rate of 1.5 cm/sec at
2 atmospheres. This burn rate increase to a maximum of 7 cm/sec at a pressur

10   of 7 to 8 atmospheres. The burn rate then decreases to a value of 2 cm/sec at a
pressure of 70 atmospheres. This behaviour makes potassium picrate a
candidate for only low pressure applications. However, for higher pressure
applications, such as for use as part of an initiation portion of the present
invention, this decrease in burn rate is not desirable since it reduces the rate of

15   pressurization of the detonator. When combined with potassium perchlorate,
however, the decrease in burn rate is essentially eliminated and the burn rate
increases essentially continuously with pressure. Accordingly, the combination of
potassium picrate and potassium perchlorate provides a particularly effective
mixture for use as the high-burn-rate pressurising initiator in the present

20   invention.

The high-burn-rate pressurising initiator also preferably provides a rapid
increase in pressure so as to provide a shock wave suitable for initiation of the
porous, powdered explosive. Generally, the high-burn-rate pressurising initiator
will provide an increase in gas pressure equal to, or greater than 2 kbar, when

25   measured inside the confinement element which contains at least a part of the
initiation portion. In practice, the pressure increase can be estimated from the
amount of expansion of the confinement tube. More preferably, the increase in
gas pressure will be greater than 5 kbar, and most preferably, will b   greater than
10 kbar.

Materials which have a high burn rate, but which do not develop a significant gas pressure increase (in accordance with the values given above) are not preferred in the operation of the present invention.

Preferred materials suitable for use in the high-burn-rate pressurising
5   initiator include materials such as potassium picrate, potassium styphnate, lead styphnate, potassium trinitrobenzoate, or alkali or alkaline earth metal salts of nitro-aromatic compounds, and in particular, nitrophenols or nitrobenzoates, or mixtures thereof. More preferably, however, the high-burn-rate pressurising initiator is a mixture of a high burn rate explosive and an oxidizer. A more
10  preferred composition for the high-burn-rate pressurising initiator is a mixture of a material having a high-burn-rate at low pressure, such as potassium picrate, potassium styphnate, lead styphnate, or potassium trinitrobenzoate together with an oxidizer such as potassium perchlorate or ammonium perchlorate. A preferred mixture of these materials comprises between 30 and 70% (by weight) oxidizer.
15  More preferably, the mixture comprises between 30 and 70% potassium picrate and 30 to 70% potassium perchlorate. More preferably, the mixture comprises between 40 and 60% potassium picrate and potassium perchlorate. Most preferably, the mixture comprises about 50% potassium picrate and about 50% potassium perchlorate.

20      With this preferred mixture, high burn rates are possible while also providing good levels of pressurization. This combination provides an improved ability to effect the transition from deflagration to detonation when combined with the PETN. This improved ability can be achieved with decreased levels of confinement and without the need for back-pressing. Thus, this preferred mixture
25  provides clear advantages over the DDT formulations of the prior art.

The materials used for the high-burn-rate pressurizing initiator preferably have a particle size small enough in at least one dir ction so that they can be located within the interstitial spacing in the porous powdered explosiv .
Accordingly, th  components of th  high-burn-rate pr ssurizing initiator
30  preferably each hav  a particle size of less than 15 microns, more preferably less

than 10 microns, and even more preferably have a particle size of 5 microns or less.

In the present application, the term "intimate mixture" describes a combination of at least two materials which have been well mixed so that, in the 5 particular mixture of interest in the present invention, the components of the high-burn-rate pressurising initiator is/are located within the interstitial spaces in the porous, powdered explosive(s).

The term "adjacent" when used in this specification means that two materials, such as the base charge and the initiating element, are located 10 sufficiently close to one another that the reaction front passes from one material to the other. Contact between the materials is generally preferred, but is not required.

The initiation portion may contain other materials to modify its performance properties. Preferably, however, the initiation portion comprises at least 10% by 15 weight of said intimate mixture of said porous, powdered explosive and said high-burn-rate pressurising initiator. More preferably, the initiation portion comprises at least 50%, and even more preferably, at least 90%, of said intimate mixture. Most preferably, however, the initiation portion comprises greater than 99% of said intimate mixture.

20     The ratio of porous powdered material to high-burn-rate pressurising initiator in the intimate mixture of the initiation portion of the initiating element is dependent on the materials selected, and the desired performance properties. However, preferably, the level of porous powdered material is at least 50% (by weight) of said intimate mixture, more preferably greater than 70% of said 25 intimate mixture, and even still more preferably, is greater than or equal to 80% of said intimate mixture. Preferably, the minimum level of high-burn-rate pr ssurizing initiator is at least 5% of said intimate mixture.

In a most preferr d embodiment, both components of the intimate mixture ar not primary explosives and thus permit the production of a detonator which is 30     free from primary explosives.

When present, the transition portion of the initiating element is located between the initiation portion and the base charge (also when present) or the closed end of the detonator. The transition portion is typically a secondary explosive which can be detonated by the reaction front passing through the

5   initiation portion. and which can detonate with sufficient energy to detonate the adjacent base charge material. A preferred material for use as the transition portion is PETN having a particle size of between 75 and 185 microns, and which has a lower density that the base charge. Preferred densities for the initiation portion are between 1.0 and 1.2 g/cc.

10   In a further aspect, the present invention also provides a composition suitable for use in an explosive detonator which comprises an intimate mixture of a porous powdered explosive having interstitial spaces, and a high-burn-rate, pressurizing initiator located within said interstitial spaces.

In a still further aspect, the present invention also provides an initiating

15   element comprising an initiation portion and optionally a transition portion characterized in that said initiation portion comprises an intimate mixture of a relatively large particle size, porous, powdered explosive having interstitial spaces, and a relatively small particle size, high-burn-rate, pressurizing initiator located within said interstitial spaces.

20   In a yet still further aspect, the present invention also provides a method of production of the detonators described. Further, the present invention also provides a method of blasting comprising initiating an explosive charge using a detonator, wherein the detonator is as described hereinabove with respect to the present invention.

25   Further objects and advantages of the present invention will be evident from the detailed description of the invention hereinbelow.

When present, the transition portion of the initiating element is located between the initiation portion and the base charge (also when present) or the closed end of the detonator. The transition portion is typically a secondary explosive which can be detonated by the reaction front passing through the
5 initiation portion and which can detonate with sufficient energy to detonate the adjacent base charge material. The transition portion may comprise PETN, RDX, HMX, Tetryl or a mixture thereof. A preferred material for use as the transition portion is PETN having a particle size of between 75 and 185 microns, and which has a lower density that the base charge. Preferred densities for the initiation portion are between 1.0 and 1.2 g/cc.

10 In a further aspect, the present invention also provides a composition suitable for use in an explosive detonator which comprises an intimate mixture of a porous powdered explosive having interstitial spaces, and a high-burn-rate pressurizing initiator located within said interstitial spaces.

In a still further aspect, the present invention also provides an initiating
15 element comprising an initiation portion and optionally a transition portion characterized in that said initiation portion comprises an intimate mixture of a relatively large particle size, porous, powdered explosive having interstitial spaces, and a relatively small particle size, high-burn-rate pressurizing initiator located within said interstitial spaces.

20 In a yet still further aspect, the present invention also provides a method of production of the detonators described. Further, the present invention also provides a method of blasting comprising initiating an explosive charge using a detonator, wherein the detonator is as described hereinabove with respect to the present invention.

25 Further objects and advantages of the present invention will be evident from the detailed description of the invention hereinbelow.

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## Brief Description of the Drawings

The invention may be more clearly understood by reference to the following detailed description of the invention, and the accompanying drawings wherein:

Figures 1 to 3 are cross-sectional drawings of in-hole detonators according

5    to the present invention; and

Figures 4 to 6 are cross-sectional drawings of surface detonators according to the present invention.

## Detailed Description of the Preferred Embodiments

The present invention is applicable to both in-hole and surface detonators.

10   Further, the detonators may be electronic, electric or non-electric. The term "detonator" is used in a general sense and is meant to include a variety of initiation devices which may also be referred to as blasting caps, initiators and the like.

The detonator may also be a "delay" detonator, by which term is meant that

15   the detonator comprises means, such as a pyrotechnic delay element, a series of delay elements (e.g. a delay "train"), an electronic timing circuit, or some other device, to cause a time delay between initiation of the igniting device and the subsequent initiation of the initiation portion and/or base charge. However, the detonator may also be an instantaneous, non-delay detonator.

20   It should be noted that the materials used in the production of the delay element (or the delay "train") are typically not gas-generating, or produce very little gas during combustion. This is in distinct contrast to the high-burn-rate pressurising initiator used in the intimate mixture of the present invention.

It should also be not d that the intimat  mixtur  may also includ  additional

25   materials. However, all percentages values discuss d herein ar  based on the weight ratios of the porous, powdered  xplosive and the high-burn-rate pressurising initiator, or ar  based on the total weight of just the initiation portion.

Other additional materials which may be included in the intimate mixture include materials such as explosives, pyrotechnics or propellants. Further, materials such as organic fuels, "inert" organic binders, and the like, which may or may not be consumed during the reaction/detonation may also be present.

5    However, preferably the levels of these additional materials is less than 25%, more preferably less than 10% and most preferably, less than 2% of the total weight of the porous, powdered explosive, the high-burn-rate pressurising initiator, and the additional material(s).

The additional material can include any suitable primary or secondary

10   explosive or initiator which is added to modify the reaction characteristics of the initiation portion, but which does not meet the criteria of being either a porous, powdered explosive or a high-burn-rate pressurising explosive. This can include, for example, materials such as lead azide, or PETN of non-acceptable particle size (e.g. less than 100 microns). However, in light of the stated goal of

15   minimizing the use of a primary explosive, it is preferred that the initiation portion be essentially free of added primary explosives.

A preferred additional material which may be used in combination with the initiation portion is a material which is a "molecular" explosive. Preferred molecular explosives are generally secondary explosive compounds wherein the

20   fuel and oxygen are present on the same molecule. Examples of preferred suitable secondary molecular explosives are non-acceptable particle sized PETN, RDX or HMX or mixtures thereof.

The level of these materials should, however, be low enough so as to not interfere with the intimate mixing of the initiation portion, and thereby interfere

25   with the ability to locate the high-burn-rate pressuring initiator within the interstitial spaces of the porous, powdered explosive.

Exampl  s of other optional additional materials which may be incorporated into the initiati  n portion includ  fuels such as finely divided solids including sulphur or carbonaceous mat  rials such as gilsonit , comminuted coke or

30   charcoal, carbon black, resin acids, sugars such as glucose or dextrose and other veg  table products such as starch, nut meal, grain meal and wood pulp; and

Other additional materials which may be included in the intimate mixture include materials such as explosives, pyrotechnics or propellants. Further, materials such as organic fuels, "inert" organic binders, and the like, which may or may not be consumed during the reaction/detonation may also be present.

5 However, preferably the levels of these additional materials is less than 25%, more preferably less than 10% and most preferably, less than 2% of the total weight of the porous, powdered explosive, the high-burn-rate pressurising initiator, and the additional material(s).

The additional material can include any suitable primary or secondary 10 explosive or initiator which is added to modify the reaction characteristics of the initiation portion, but which does not meet the criteria of being either a porous, powdered explosive or a high-burn-rate pressurising explosive. This can include, for example, materials such as lead azide, or PETN of non-acceptable particle size (e.g. less than 100 microns). However, in light of the stated goal of 15 minimizing the use of a primary explosive, it is preferred that the initiation portion be essentially free of added primary explosives.

A preferred additional material which may be used in combination with the initiation portion is a material which is a "molecular" explosive. Preferred molecular explosives are generally secondary explosive compounds wherein the 20 fuel and oxygen are present on the same molecule. Examples of preferred suitable secondary molecular explosives are non-acceptable particle sized PETN, RDX or HMX or mixtures thereof.

The level of these materials should, however, be low enough so as to not interfere with the intimate mixing of the initiation portion, and thereby interfere 25 with the ability to locate the high-burn-rate pressuring initiator within the interstitial spaces of the porous, powdered explosive.

Examples of other optional additional materials which may be incorporated into the initiation portion include fuels (typically organic fuels) such as finely divided solids including sulphur or carbonaceous materials such as gilsonite, 30 comminuted coke or charcoal, carbon black, resin acids, sugars such as glucose or dextrose and other veg table products such as starch, nut meal, grain meal and wood pulp; and

mixtures thereof. Also materials such as propellants and/or gas-generating compounds such as nitrocellulose or sodium azide based propellants, and the like, may be added. Further, binders (preferably energetic binders) such as polymeric materials (including nitrocellulose or GAP (glycidyl azide polymer) can

5    also be included.

Additionally, or alternatively, the formulations of the present invention may be granulated in order to improve their flow properties and in order to reduce dusting. Granulation can be done by forcing a damp mixture through a certain screen size to form granules which are then dried. Granulation can also be done

10   by adding a granulating agent. This agent is usually dissolved in a liquid and mixed with the energetic material(s). The damp mixture is also typically forced through a certain screen size to form granules which are then dried. In this case, the granulating agent acts as a binder to help hold the granules together. When granulated, the granules produced should have a particle size which is at least as

15   large as the particle size of the crystals of the porous, powdered explosive. Accordingly, the present invention also includes detonators, and a production process, wherein all or part of the materials utilized have been subjected to a granulation process.

Granulating agents are well known within the explosives industry. One

20   suitable granulating agent for the formulations described herein is a hydroxypropyl methylcellulose material sold under the trade mark Methocel K4MS (available from Dow Chemical).

The amount of initiation portion present in the initiating element of the detonators of the present invention can vary widely depending on its composition,

25   detonator design, and desired output. These parameters have been previously discussed. For typical situations in a standard sleeve having a 3.8 mm inside diameter (ID), the level of initiation portion is preferably between 10 and 200 mg, more preferably between 50 and 150 mg, and most pr ferably betwe n 100 and 150 mg.

30   The amount of transition portion present in the initiating element can also vary widely depending on composition, design and desired output. The transition

portion can also be eliminated under some circumstances. Accordingly, the level of transition portion can, for example, vary from 0 to 200 mg, but more preferably is between 50 and 150 mg. Most preferably the level of transition portion is between 100 and 130 mg.

5          The initiation portion and the transition portion (when present) together form the initiating element. Using the initiating element of the present invention, less confinement of the initiating element is required. Accordingly, the confinement may consist of a simple metal sleeve which is adapted to be fitted within a standard detonator shell. The confinement sleeve is preferably a copper, steel or

10        stainless steel sleeve which is sized so as to closely fit within the shell of a standard detonator. For example, in a standard detonator having an inside diameter (ID) of 6.8 mm, the confinement sleeve will preferably have an outside diameter (OD) of 6.3 mm and a wall thickness of between, for example, 0.1 to 1.5 mm. However, the inner diameter of the confinement sleeve can vary depending

15        on the amount of confinement desired. Most preferably, the confinement sleeve has a wall thickness of about 1.25 mm and is made of steel because of its high strength to mass ratio.

           With the formulations of the present invention, it should be noted that the requirement for back-confinement is eliminated, and that there is no need for a

20        cup-shaped confinement means with small apertures. Accordingly, the detonators of the present invention have manufacturing advantages over the prior art DDT detonators.

           Under some configurations, it is also possible to eliminate the need for complete confinement of all of the initiating element. Generally, however, it is

25        typically preferable to provide confinement at at least the interface where the initiation portion is first initiated. This aids in ensuring that the DDT reaction has sufficient confinement to transfer from deflagration to detonation within an acceptably short l ngth of th  initiation portion and ther by is abl  to  ffect detonation of the transition portion or the bas  charge.

Preferably, all materials used in the production of the intimate mixture of the initiation portion, or more generally, all materials used in the production of the detonators of the present invention, are powdered materials at 20 ° C.

Detonators of the present invention are primarily used in in-hole
5   applications. However, as previously stated, detonators of the present invention may be used in surface applications. These surface detonators typically contain a smaller base charge or omit the base charge. Alternatively, the base charge may be a reduced energy base charge comprising, for example, PETN together with an inert salt.

10  When present, the base charge may be any of the materials described hereinabove with respect to prior art detonators. However, preferably the base charge used in the detonators of the present invention is a secondary explosive, and more preferably is a molecular secondary explosive. The amount of base charge present will also vary depending on the desired features of the detonator.
15  However, typical levels for the base charge in an in-hole detonator will range from 100 to 900 mg, and more preferably will be between 200 and 800 mg. Surface detonators will typically contain less of a base charge or a less energetic base charge.

Further, in a surface detonator, the density and length of the initiation
20  portion can be tailored to achieve a low order detonation (i.e. does not achieve full detonation) which does not fragment the confinement sleeve. This design has the advantage that a low order detonation can be used to initiate adjacent shock tubes while reducing the risk of damage resulting from the fragments created caused by a high order detonation. In this embodiment of a surface detonator, th
25  transition charge and/or the base charge can be omitted.

Alternatively, the base charge can be diluted (by an essentially inert substance) or a low density base charg   can b   used in order to produce a lower pressure detonation which is more suitable for initiation of shock tub  . The lower pressure also reduces fragm  nts and th  refore, reduces the damages which
30  might be caused by high density, and thus, high pressure base charges.

With the exception of the DDT element, in general, and the composition of the initiating element, in particular, production of the detonators of the present invention is essentially identical to prior art techniques. These techniques for production are well known to those skilled in the art. Using known techniques, all

5    or a portion of the initiating element components may be added to the detonator shell with the confinement sleeve, and pressed to the desired density. Alternatively, all or a portion of the initiating element components may first be pressed into the confinement sleeve prior to inserting the sleeve into the detonator shell.

10    The addition of a delay element to provide a delay detonator should have little or no impact on the operation of the detonators of the present invention, and manufacture of the delay element is a standard technique in the explosive detonator technology.

The detonator igniting device can be any suitable device which will initiate

15    the delay element and/or directly initiate the initiation portion. Suitable igniting devices include electric "matches", bridge wires, shock tube, safety fuse, detonating cord, or the like, which are inserted into the open end of the detonator shell and which are capable of generating a flame and/or shock wave. Other devices which may be included as igniting devices in the detonators of the

20    present invention include electronic detonator "hotspots", "slapper" detonators, lasers which are capable of generating an energy pulse through, for example, a fibre optic cable, and the like.

As previously discussed, a benefit of using the formulations of the present invention is that the initiating element is able to make the transition from

25    deflagration to detonation in a standard thin wall detonator with limited levels of confinement, and do not require additional heavy confinement means, such as heavy walled steel or copper sl ev s and the like. Use of th s simpler confinement means is pref rable to the confinement means described in the DDT prior art. This improv ment provides manufacturing advantag s since the design

30    of the deton at r may be ssentially the same as for prior art detonators. Th only significant diff rence is the replacement of the primary explosive by a simpl

cylindrical DDT initiating element which can be manufactured using processes similar to known processes such as, the processes used to produce rigid technology delay elements.

A preferred formulation for the initiation portion of the initiating element, according to the present invention, for use in both surface or in-hole detonators comprises a mixture of 5 to 15% potassium picrate, 5 to 15% potassium perchlorate and 70 to 90% PETN. In this embodiment, the preferred particle size of the materials is as follows: (i) potassium picrate - between 0.5 and 3 microns; (ii) potassium perchlorate - between 1 and 10 microns; and (iii) PETN - between 80 and 120 microns.

It may also be necessary, as is common in this art, to adjust the density of the initiation portion by pressing the mixture during production. Preferably, the density of the initiation portion after pressing is between 1.2 and 1.5 g/cc. However, this may vary depending on the materials selected for production of the initiation portion and may vary depending on the level of confinement selected.

A preferred formulation for the transition portion of the initiating element is the use of PETN having a particle size of between 75 and 180 microns, with a number average particle size of at least 100 microns, and pressing to a density of 1.0 to 1.2 g/cc.

This combined initiating element formulation has demonstrated the ability to produce detonators having properties which are generally equivalent to prior art detonators containing primary explosives. However, a feature of the initiating element of the present invention is that the energy output and VOD, as well as other properties such as sensitivity, heat stability, and the like may be adjusted or modified by changes to the initiating element formulations.

Preferably, the initiating element is formulated to provide acceptable performance standards over a wid  temperature range from at least -40 ° C to great r than 120 ° C. Also, it is pr ferr d that the initiating l ment b  formulat d so as to b  of roughly equivalent length to the initiation portions of prior art detonators. This may be, for example, a length of about 15 to 18 mm but this can vary depending on the detonator design. This permits the detonators produced in

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With exception of the DDT element, in general, and the composition of the initiating element, in particular, production of the detonators of the present invention is essentially identical to prior art techniques. These techniques for production are well known to those skilled in the art. Using known techniques, all

5    or a portion of the initiating element components may be added to the detonator shell with the confinement sleeve, and pressed to the desired density. Alternatively, all or a portion of the initiating element components may first be pressed into the confinement sleeve prior to inserting the sleeve into the detonator shell.

10    The addition of a delay element to provide a delay detonator should have little or no impact on the operation of the detonators of the present invention, and manufacture of the delay element is a standard technique in the explosive detonator technology.

The detonator igniting device can be any suitable device which will initiate

15    the delay element and/or directly initiate the initiation portion. Suitable igniting devices include electric "matches", bridge wires, shock tube, safety fuse, detonating cord, or the like, which are inserted into the open end of the detonator shell and which are capable of generating a flame and/or shock wave. Other devices which may be included as igniting devices in the detonators of the present

20    invention include electronic detonator "hotspots", "slapper" detonators, lasers which are capable of generating an energy pulse through, for example, a fibre optic cable, and the like. Typically, the detonator comprises an electronic detonator.

As previously discussed, a benefit of using the formulations of the present

25    invention is that the initiating element is able to make the transition from deflagration to detonation in a standard thin wall detonator with limited levels of confinement, and do not require additional heavy confinement means, such as heavy walled steel or copper sleeves and the like. Use of these simpler

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confinement means is preferable to the confinement means described in the DDT
prior art. This improvement provides manufacturing advantages since the design
of the detonator may be essentially the same as for prior art detonators. The only
significant difference is the replacement of the primary explosive by a simple
5    cylindrical DDT initiating element which can be manufactured using processes
similar to known processes such as, the processes used to produce rigid
technology delay elements.

A preferred formulation for the initiation portion of the initiating element,
according to the present invention, for use in both surface or in-hole detonators
10   comprises a mixture of a material having a high burn rate at low pressure, such as
5 to 15% potassium picrate, 5 to 15% of an oxidiser, such as potassium
perchlorate which together form the pressurising initiator and 70% to 90% PETN.
In this embodiment, the preferred particle size of the materials is as follows: (i)
potassium picrate – between 0.5 and 3 microns; (ii) potassium perchlorate –
15   between 1 and 10 microns; and (iii) PETN – between 80 and 120 microns.

It may also be necessary, as is common in this art, to adjust the density of
the initiation portion by pressing the mixture during production. Preferably, the
density of the initiation portion after pressing is between 1.2 and 1.5 g/cc.
However, this may vary depending on the materials selected for production of the
20   initiation portion and may vary depending on the level of confinement selected.

A preferred formulation for the transition portion of the initiating element is
the use of PETN having a particle size of between 75 and 180 microns, with a
number average particle size of at least 100 microns, and pressing to a density of
1.0 to 1.2 g/cc.

25          This combined initiating element formulation has demonstrated the ability to
produce detonators having properties which are generally equivalent to prior art
detonators containing primary explosives. However, a feature of the initiating
element of the present invention is that the energy output and VOD, as well as

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other properties such as sensitivity, heat stability, and the like may be adjusted or modified by changes to the initiating element formulations

Preferably, the initiating element is formulated to provide acceptable performance standards over a wide temperature range from at least -40°C to

5    greater than 120°C. Also, it is preferred that the initiating element be formulated so as to be of roughly equivalent length to the initiation portions of prior art detonators. This may be, for example, a length of about 15 to 18 mm but this can vary depending on the detonator design. This permits the detonators produced in

accordance with the present invention to be of similar length and size to prior art detonators.

One significant feature of the detonators of the present invention is that all materials used for production can be non-primary explosives. Accordingly, the
5   detonators produced may be handled without the precautions necessary for handling primary explosives. Also, because of the low level or absence of primary explosive in the detonators in the preferred embodiments of the present invention, the detonators produced show improved impact resistance and improved propagation resistance over conventional detonators. Impact resistance
10   is a measurement to determine whether a detonator will cause initiation of an outgoing shock tube or detonating cord when the detonator is subjected to the impact of a steel weight dropped from a measured height. For the purposes of this specification, the steel weight is 25 pounds (11.4 kg). Standard detonators of the prior art typically initiate the shock tube or the detonating cord when the steel
15   weight is dropped from a height of 7 feet (2.15 metres) or less for surface detonators, or 4 feet (1.2 metres) or less for in-hole detonators. Accordingly, an impact resistant detonator for the purposes of this specification is one which does not initiate shock tube or detonating cord when the steel weight is dropped from a height of 15 feet (2.3 metres) for a surface detonator and 10 feet (3.1 metres) for
20   an in-hole detonator.

Accordingly, the present invention provides detonators which are impact resistant, according to the definition herein provided, and also provides a process for the production of detonators which are impact resistant.

In a similar manner, the detonators of the present invention have improved
25   resistance to propagation. This property is defined as the ability to resist detonation by a detonator caused by the detonation of an adjacent detonator.

Accordingly, th pr s nt invention also provides a surface or in-hole det nator, and a process for producing a detonator, which is propagation resistant. Currently, th formulations and design of the present invention
30   facilitates the development of detonators and low cost packaging which complies with current UN standard 1.4B packaging classification requirem nts.

With respect to the drawings, it should be noted that a major advantage of the detonators of the present invention is that they can be produced in a fashion similar to existing prior art detonators. Accordingly, the detonators are similar in appearance to prior art detonators with the exception that the traditional, prior art,

5    initiation portions have been replaced by the compositions described in the present invention.

In Figure 1 a non-electric, in-hole delay detonator is shown wherein 1 designates a metal tubular shell with an inside diameter of 6.7 mm, and closed at its bottom end. Within shell 1 is a base charge 2 of 800 mg of PETN (greater than

10    200 micron particle size) pressed to a density of 1.5 g/cc. Adjacent the base charge 2 is initiating element 3 which consists of a transition portion 4 and an initiation portion 5. Initiation portion 5 is held within confinement sleeve 8 and is an intimate mixture of 10% potassium picrate (2 to 20 micron particle size), 10% potassium perchlorate (3 micron particle size) and 80% PETN (75 to 180 micron

15    particle size) which mixture has been dry mixed and pressed to a density of 1.5 g/cc. Transition portion 4 is also held within confinement sleeve 8 and consists of PETN (75 to 180 micron particle size) which has been pressed to a density of 1.1 g/cc. Sleeve 8 is a cylindrical steel sleeve which has an outside diameter of 6.3 mm and an inside diameter of 3.8 mm.

20    A delay train of a mixture of red lead, silicon and barium sulphate is shown at 15 and is contained within a metal tube 16. Above delay train 15 is the open end of an inserted shock tube 10 which rests against an anti-static cup 11. Shock tube 10 is held centrally and securely in tube 1 by means of closure plug 12 and crimp 13. When shock tube 10 is initiated at its remote end (not shown) a

25    reaction front passes along the tube, through anti-static cup 11 and ignites delay charge 15. Delay charge 15 burns down to initiation portion 5 at a controlled rate so as to provid  the desired delay tim . Initiation portion 5 subsequently effects initiation of transition  lement 4. As th  reaction front passes through initiating el ment 3, a DDT reaction occurs so that initiating element 3 goes through a

30    deflagration to detonation transition. Accordingly, a portion of initiating element 3

eventually detonates. This detonation of initiating element 3 subsequently causes the detonation of base charge 2.

In Figure 2, an electric delay detonator is shown which is similar to the non-electric detonator of Figure 1. In this embodiment, however, the shock tube 5    assembly is replaced with electric match head 26 which is connected to a pair of electrically conducting leads 27. Leads 27 pass through a rubber insert 28 which insert is crimped into place by a crimp 29 in shell 1. Otherwise, all other features are identical to the embodiment described in Figure 1. In Figure 2, and all other subsequent figures, like numerals are used to represent equivalent features.

10    In operation, an electrical signal passes through leads 27 and causes match head 26 to initiate. The initiation of match head 26 causes delay train 15 to begin burning at its upper end as in the detonator of Figure 1. From this point, operation of this detonator is identical to the detonator of Figure 1.

In Figure 3 a non-electric, instantaneous detonator is shown which is 15    identical to the detonator described in Figure 1 with the exception that delay element 15 and metal tube 16, have been removed so that the reaction front from shock tube 10 directly initiates initiation portion 5. Again, from this point, operation of this detonator is identical to the detonator of Figure 1.

In Figure 4, a non-electric delay surface detonator is shown which is 20    essentially identical to the detonator of Figure 1. However, in this surface detonator, base charge 2 of Figure 1 has been replaced with a lower output base charge 2A consisting of 200 mg of a mixture of 70% by weight PETN and 30% talc.

In Figure 5, an electric surface detonator is shown which is similar to Figure 25    2. However, base charge 2 has been removed. Detonation of initiating element 3 is utilized to provide initiation of any shock tubes (not shown) which are adjacent to detonator 1.

In Figur  6, a non-electric surface detonator is shown which is similar to the detonator shown in Figure 4 with th    xception that bas   charge 2A and 30    transition portion 4 has been removed. In this embodim  nt, a larger portion of initiation portion 5 is used alone and undergoes th   DDT reaction. Th   resulting

detonation is utilized to provide initiation of any shock tubes (not shown) which are adjacent to detonator 1.

Numerous variations and modifications of these devices are commonly known within the industry. For example, shock tubes or electric match heads can

5     be replaced by a variety of devices which can effect initiation of the delay train, or instantaneous initiation of the initiation portion in a non-delay detonator. Further, the initiation portion can be directly initiated by a suitable device in an electronic detonator which eliminates the delay train in a delay detonator.

The utility of the invention will now be described, by way of example only, by

10    reference to the following examples.

## Examples

A series of detonators (both surface and in-hole types) were prepared using formulations according to the present invention. The detonators were tested for suitability for use. The detonator design and results were as follows:

15    **Surface Detonators**

**Example 1**

140 mg of an initiation portion consisting of a mixture of 10 parts of potassium picrate and 90 parts of PETN was poured into a cylindrical steel element 18 mm long, 6.3 mm OD, 3.8 mm id and pressed at 1.5 g/cc density. The remaining

20    space in the element was filled with 100 micron PETN (as a transition portion) and was pr ssed to a density of 1.1 g/cc. An adhesive paper retaining cover was applied and the el ment inverted and loaded onto 50 mg of PETN (as a base charge) contained in a 6.7 mm ID detonator shell. A 75 ms delay was placed on top of the steel element and a lead sealer element was crimped on top. The

detonator was placed in a connector block with 3 shock tubes ahead of the base charge and one to each side. When the detonator was fired using a line of shock tube all the tubes were initiated at both 20° and - 40° C. The shrapnel produced was less than from a conventional surface detonator containing 300 mg of lead

5     azide.

### Example 2

The base charge in Example 1 was replaced by 200 mg of a mixture of 70 parts of PETN and 30 parts of talc. The talc was present to dilute the output of the base charge by reducing its detonation velocity and reduce shrapnel production. When

10    fired 5 shock tubes arranged as in Example 1 were initiated and the shrapnel production was less than from a conventional surface detonator.

### Example 3

The base charge in Example 1 was removed . When fired up to 6 tubes arranged in a 3 by 2 arrangement ahead of the detonator could be initiated as could 5

15    tubes arranged as in Example 1 at 20° C.   At –40° C, 4 out of 5 tubes wer initiated in the latter configuration. The detonator also gave less shrapnel output than a conventional surface detonator.

### Example 4

The initiating element from the detonator in Example 3 was filled only with the

20    initiation portion and all other aspects of the detonator remaining the same. When fired it was able to initiate up to 6 shock tubes arranged in a 3 by 2 pattern and produced minimal shrapnel.

### Exampl  5

Steel confin  ment elements, 18 mm length 6.3 mm OD 3.8 mm ID, were filled with

25    315 mg of the initiation mixture of Example 1 and pressed to 1.4 to 1.5 g/cc density.  The element was loaded into a detonator shell containing a mixture of 10%  60 micron potassium picrate and 90% 75-180 micron PETN confined in an

inverted brass cup, with a hole in its bottom. The delays were loaded on top of the steel element. The brass cups had an OD of 6.40 mm, an ID of 5.73 mm and the diameter of the hole in its bottom was 2.44 mm. The detonators were tested in the 5 shock tube configuration described in Example 1. The number of shock

5    tubes initiated for the different configurations are shown in the Table 1. The steel elements did not shatter and produced no shrapnel.

Table 1: Number of shock tubes (out of 5) initiated for different deflagrative element length and base charge configurations

| Base Charge Vol. | Base charge density | Ignition Charge Length mm | | | | |
|---|---|---|---|---|---|---|
| | | 18 | 14.5 | | 10 | |
| cc | g/cc | 20° C | 20° C | -36° C | 20° C | -36° C |
| 0.24 | 1.35 | 2 | | | | |
| | 1.1 | 4 | | | | |
| | 1 | 5 | | | | |
| | 0.9 | 5, 5 | 5 | | | |
| | 0.45 | | 5 | 5 | 5 | 5 |
| 0.14 | 0.9 | | 5 | | 0 | |

## In-Hole Detonators

5  ## Example 6

140 mg of a mixture of 75-180 micron PETN (80% by mass), 2-20 micron potassium picrate (10%) and 3 micron potassium perchlorate (10%) was poured into a 18 mm length 6.3 mm OD, 3.8 mm ID stainless steel tube and pressed to a density of 1.5 g/cc. The remaining space of the tube (the transition portion) was

10  filled with 130 mg of 75 - 180 micron PETN and pressed to a density of 1.1 g/cc. The initiating element form was inserted into a 6.5 mm ID aluminum detonator shell containing 0.8 g PETN base charge pressed to 1.5 g/cc density. Pyrotechnic delay elements were placed on top of the initiating el ment followed by a shock tube. Four detonators were test d on aluminum witness blocks and

15  all four detonators produced dents of more than 2 mm depth.

Example 7

Three charge weights of 100, 120 and 140 mg of the same initiation mixture as in
Example 6 were pressed to densities of 1.2, 1.3, 1.4 and 1.5 g/cc in stainless
steel tubes (6.3 mm OD and 3.8 mm ID) of lengths varying from 15.5 to 18 mm.

5    These produced initiation portions of various lengths depending on the mass and
density combination. The transition portion was kept at a constant length of 10
mm by filling in the remaining space of the confinement tube with 130 mg of 75 -
180 micron PETN and pressing to a density of 1.1 g/cc. The initiating elements
were tested in the same configuration as Example 6 except that the base charge

10   was made of an inert material, sodium chloride, pressed to a density of 1.7 g/cc,
which closely simulates the dynamic response of PETN at 1.5 g/cc. All initiating
elements except one shattered. The only intact piece was from the 100 mg
initiation portion with a 1.4 g/cc density which was expanded to 8.9 mm. It is
believed that this resulting pressure was more than enough to cause the base

15   charge to fully detonate. These tests show that an initiation portion with mass
above 100 mg in density range of 1.2 to 1.5 g/cc and the 10 mm column length of
transition charge can cause the base charge to detonate.


Example 8

Two electric detonators were made as described in respect of Figure 2. On

20   initiation, both detonators produced dents in the aluminum witness block of more
than 2 mm.


Example 9

140 mg of an initiation portion consisting of potassium picrate (10%) and PETN
(90%), as used in Example 6, was used as the initiation portion in Example 6. 10

25   detonators were made using procedure as Example 6 and when they were fired
on aluminum witness blocks. All produced dents of more than 2 mm.

Example 10

244 mg of the initiation portion as in Example 6 was loaded into 18 mm long steel

tubes of 6.3 mm OD 5.07 mm ID at a density of 1.4 g/cc and the remaining space

was filled with a transition portion of PETN pressed to 1.1 g/cc. Two detonators

5    were made as in Example 6 using these thin walled steel DDT elements. When

fired, the two detonators produced dents of more than 2 mm deep in the

aluminum witness blocks.


Example 11

225 mg of the initiation portion as in Example 6 was loaded into 18 mm long

10   copper tubes of 6.3 mm OD 5.16 mm ID at a density of 1.35 g/cc and the

remaining space was filled with a transition portion of PETN pressed to 1.1 g/cc.

Two detonators were made as in Example 6 using these thin walled copper tubes.

When the shock tubes were fired, the two detonators produced dents of more

than 2 mm deep in the aluminum witness blocks.


15   Example 12

A test was carried out to evaluate the effect of back venting, which simulates a

potential application problems for DDT detonators. These problems are

commonly encountered in field application situations and could be caused, for

example, by physical distortion of the detonator shell by transmitted shock from

20   adjacent boreholes or misalignment of the delay elements in the manufacture

process.  Two detonators were prepared as in Example 6 with the addition of a

1.54 mm thick washer (6.4 mm OD and 3.4 mm ID) between the delay element

and the initiating element. A venting hole was created in the washer by cutting a

1.25 mm slot radially on the washer and the corresponding location of the

25   aluminum detonator shell was also cut to allow venting. When the shock tubes

w r  fired, both detonators fully detonated producing dents of more than 2 mm on

th  aluminum blocks.

Example 13.

Example 12 was repeated with the initiation mixture of Example 9. Two
detonators were made and they did not produce any dents on the aluminum and
the OD of the stainless steel tube expanded to only 6.39 mm.

5   Example 14

170 mg of a dry mix of 2-20 micron potassium picrate (10% w/w) and 90-425
micron PETN (90% w/w) was poured into a 28 mm length, 6.3 mm OD, 3.3 mm ID
zinc element and pressed at 4.6 kPa. The space in the element was filled with
100 micron (approximate size) recrystallised PETN fraction prepared by
10  controlled crystallization from acetone/water. This charge was pressed at 1.2
kPa. The space left in the element was filled with loose 100 micron PETN and an
adhesive paper circle placed over the end of the zinc element. The zinc element
was inverted and loaded into a 6.7 mm ID aluminum detonator shell containing a
0.8 g PETN base charge pressed at 5.8 kPa. When initiated by a shock tube, 10
15  out of 10 detonators fired as indicated by witness plates and by damage to the
zinc elements.

Example 15

The potassium picrate in Example 14 was replaced by 3-20 micron potassium
styphnate. Five out of 5 detonators fired successfully.

20  Example 16

The potassium picrate in Example 14 was replaced by 10-30 micron potassium
trinitrobenzoate. Five out of 5 detonators fired successfully.

Example 17

120 mg of a mix of ultra fine PETN (granular shaped particle with averag   2
25  micron particle size, surface area ~6800 cm²/g) (80% by mass), 2-20 micron
potassium picrate (10%) and 3 micron potassium perchlorate (10%) was poured
into a 18 mm length 6.3 mm OD, 3.8 mm ID stainless steel sleeve and pressed to

a density of 1.3 g/cc. The remaining space of the tube (the transition portion) was filled with 150 mg of inert sodium chloride and pressed to a density of 1.3 g/cc. The initiating element was inserted into a 6.5 mm ID aluminum detonator shell containing 0.8 g sodium chloride inert base charge pressed to 1.7 g/cc density.

5   Pyrotechnic delay elements were placed on top of the initiating element followed by a shock tube. Three detonators were fired and the average diameter of the expanded steel sleeves was 6.46 mm and the corresponding maximum transient pressure was estimated to be about 3 kbar. The tests were repeated with three other detonators prepared using a larger size PETN (spheroidal shaped with

10   average particle size of 160 microns, surface area ~ 210 cm$^2$/g). These three detonators were fired and the average diameter of the expanded steel sleeves was 6.71 mm, the corresponding maximum transient pressure was estimated to be about 6.5 kbar. These experiments demonstrate the utility of the larger PETN particle size in the present invention.

15   **Example 18**

To illustrate the effect of particle geometry on the effectiveness of the present invention, two types of PETN particles were used. One type had a spherical shape with an aspect ratio of about one and the other had an elongated prismatic shape with an average aspect ratio of about 4. The diameter range of both were

20   75 to 180 microns. Example 17 was repeated with two initiation portions using these two types of PETN. 175 mg of these initiation portions were poured into 20 mm length, 6.3 mm OD, 3.8 mm ID stainless steel sleeves and pressed to a density of 1.4 g/cc. The remaining space of the tube (the transition portion) was filled with 150 mg of inert sodium chloride and pressed to a density of 1.3 g/cc.

25   These elements were prepared and fired as in Example 12. The average expanded element diameters were found to be 7.55 and 7.1 mm for the particles with aspect ratios of 4 and 1 r spectively. The corresponding stimated pressures were 15 and 11 kbar respectively.

Example 19

For comparison, Example 14 was repeated but with a transition portion consisting of PETN (specific surface area of 3300 $cm^2/g$) at a density of 1.6 g/cc as described by Dinegar in US patent No. 4316412. Because of the high density,

5    this charge was pressed first. 170 mg of the potassium picrate-PETN composition of Example 14 was pressed on top and the resulting "initiating element" was loaded into a shell. When initiated by a shock tube, the "initiating element" deflagrated and split the confinement sleeve without fragmenting it. The base charge was not initiated.

10        Similar results were obtained when PETN with a specific surface area of 3300 $cm^2/g$ was used in both the initiation portion and transition portion. These combinations are therefore, not suited to lower confinement conditions as exemplified in the present invention.

           Having described specific embodiments of the present invention, it will be

15    understood that modifications thereof may be suggested to those skilled in the art, and it is intended to cover all such modifications as fall within the scope of the appended claims. Additionally, for clarity and unless otherwise stated, the word "comprise" and variations of the word such as "comprising" and "comprises", when used in the description and claims of the present specification, is not

20    intended to exclude other additives, components, integers or steps.